International Journal of Engineering Inventions
e-ISSN: 2278-7461, p-ISSN: 2319-6491
Volume 15, Issue 5 [May 2026] PP: 204-207

Integration Of the Entropy Method and The Ram Method for Multi-Objective Optimization of the 3x13 Steel Grinding Process

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Abstract
Grinding is a machining method commonly used for manufacturing products requiring high precision in the mechanical engineering industry. This study performs multi-objective optimization of the grinding process for 3X13 steel on a surface grinding machine. An experimental design consisting of nine experiments based on the Taguchi method was conducted. In each experiment, three cutting parameters were varied, including workpiece velocity, feed rate, and depth of cut. Four objectives, also referred to as criteria, were measured in each experiment, namely surface roughness (Ra), cutting force component in the x-direction (Fx), cutting force component in the y-direction (Fy), and cutting force component in the z-direction (Fz). The ENTROPY method was used to determine the weights of the criteria, while the RAM method was employed to solve the multi-objective optimization problem. The optimal values of workpiece velocity, feed rate, and depth of cut were found to be 10 (m/min), 4 (mm/stroke), and 0.01 (mm), respectively. Under these optimal cutting conditions, the obtained values of Ra, Fx, Fy, and Fz were 0.49 (μm), 18.4 (N), 15.2 (N), and 28.4 (N), respectively.

Keywords: *surface grinding, 3X13 steel, multi-objective optimization, ENTROPY method, RAM method*

Date of Submission: 17-05-2026 Date of acceptance: 31-05-2026

I. Introduction

Grinding is a very common machining process in manufacturing industries. This method is often used for machining products requiring high dimensional accuracy. To maximize the advantages of the grinding process, optimization studies are necessary. Numerous studies have been conducted to optimize grinding processes in order to simultaneously satisfy multiple performance objectives. Previous studies indicate that various optimization algorithms and weighting methods have been applied for solving multi-objective optimization problems. However, no study has yet integrated the ENTROPY weighting method with the RAM algorithm for multi-objective optimization of grinding processes. This research gap motivated the present study.

II. Materials and Methods

2.1 Experimental System

The experimental specimens were made of 3X13 steel with dimensions of 40 mm × 25 mm × 8 mm. The chemical composition of the main alloying elements is presented in Table 1. Surface grinding experiments were carried out using an APSG-820/8A grinding machine manufactured in Taiwan. Surface roughness was measured using an SJ-201 roughness tester manufactured in Japan. Cutting force components were measured using a KISTLER dynamometer manufactured in Germany. To minimize random measurement errors, each response parameter was measured at least three times, and the average value was used.

Table 1. Chemical composition of 3X13 steel

C (%)	Si (%)	Mn (%)	P (%)	S (%)	Cr (%)	Ni (%)	Mo (%)
1.03	0.23	0.31	0.022	0.022	11.71	0.18	0.92

2.2 Experimental Matrix

During the experiments, three cutting parameters were varied, namely workpiece velocity, feed rate, and depth of cut. Each parameter was tested at three levels corresponding to coded levels 1, 2, and 3. The experimental matrix was designed according to the Taguchi method with nine experiments.

Table 2. Input Parameters

Parameter	Unit	Symbol	Value at level		
			1	2	3
Workpiece velocity	m/min	v	5	10	15
Feed-rate	mm/stroke	f	4	6	8
Depth of cut	mm	t	0.005	0.01	0.015

Table 3. Experimental Matrix

Exp.	Code value			Real value		
	v	f	t	v(m/min)	f(mm/stroke)	t(mm)
#1	1	1	1	5	4	0.005
#2	1	2	2	5	6	0.01
#3	1	3	3	5	8	0.015
#4	2	1	2	10	4	0.01
#5	2	2	3	10	6	0.015
#6	2	3	1	10	8	0.005
#7	3	1	3	15	4	0.015
#8	3	2	1	15	6	0.005
#9	3	3	2	15	8	0.01

2.3 Experimental Results

The values of Ra, Fx, Fy, and Fz were measured in each experiment. The results show that the minimum values of Ra, Fx, Fy, and Fz were obtained in different experiments, indicating that no single experiment simultaneously minimized all criteria. Therefore, the RAM algorithm was employed to rank the alternatives after calculating the criteria weights using the ENTROPY method.

Table 4. Experimental Results

Exp.	Input parameters			Responses			
	v(m/min)	f(mm/stroke)	t(mm)	Ra (μm)	Fx (N)	Fy (N)	Fz (N)
#1	5	4	0.005	0.82	21.7	11.3	27.1
#2	5	6	0.01	0.62	34.5	20.5	24.3
#3	5	8	0.015	0.75	39.4	16.4	26.2
#4	10	4	0.01	0.49	18.4	15.2	28.4
#5	10	6	0.015	0.51	22.5	20.6	30.4
#6	10	8	0.005	0.41	29.6	19.8	31.2
#7	15	4	0.015	0.94	31.7	22.7	22.8
#8	15	6	0.005	0.82	32.7	28.6	30.6
#9	15	8	0.01	0.73	28.1	18.4	31.5

2.4 ENTROPY Method

Assume that m experiments are conducted and n output parameters are measured. Let xij denote the value of the j-th output parameter in the i-th experiment. The ENTROPY weighting method is implemented according to the following steps:

Step 1: Determine the normalized values of the criteria according to Equation (1).

$$n_{ij} = \frac{x_{ij}}{m + \sum_{i=1}^{m} x_{ij}^2} \tag{1}$$

Step 2: Calculate the entropy measure for each parameter according to Equation (2).

$$e_j = \sum_{i=1}^{m}\left[n_{ij} \times ln(n_{ij})\right] - \left(1 - \sum_{i=1}^{m} n_{ij}\right) \times ln\left(1 - \sum_{i=1}^{m} n_{ij}\right) \quad (2)$$

Step 3: Determine the weight of each parameter according to Equation (3).

$$w_j = \frac{1 - e_j}{\sum_{j=1}^{n}(1 - e_j)} \quad (3)$$

2.5 RAM Algorithm

The steps of the RAM method for ranking alternatives are as follows:
Step 1: Similar to Step 1 of the ENTROPY method.
Step 2: Normalize the data according to Equation (4).

$$r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \quad (4)$$

Step 3: Calculate weighted normalized values according to Equation (5), where wj is the weight of the j-th criterion.

$$y_{ij} = w_j \cdot r_{ij} \quad (5)$$

Step 4: Calculate the weighted normalized scores according to Equations (6) and (7).

$$S_{+i} = \sum_{j=1}^{n} y_{+ij} \quad if \quad j \in B \quad (6)$$

$$S_{-i} = \sum_{j=1}^{n} y_{-ij} \quad if \quad j \in C \quad (7)$$

Step 5: Calculate the score of each alternative according to Equation (8).

$$RI_i = \sqrt[2+S_{-i}]{2 + S_{+i}} \quad (8)$$

Step 6: Rank the alternatives in descending order of their scores.

III. Results and Discussion

By applying Equations (1) to (3), the weights of Ra, Fx, Fy, and Fz were calculated as 0.364, 0.208, 0.218, and 0.210, respectively.

Using Equations (4) to (8), the RIi scores for each experiment were calculated. The results indicate that Experiment #4 achieved the highest ranking among all conducted experiments. Accordingly, the optimal values of workpiece velocity, feed rate, and depth of cut were determined as 10 (m/min), 4 (mm/stroke), and 0.01 (mm), respectively. Under these optimal cutting conditions, the corresponding values of Ra, Fx, Fy, and Fz were 0.49 (µm), 18.4 (N), 15.2 (N), and 28.4 (N), respectively.

Table 5. Scores and Rankings of the Experiments

Exp.	Ra (µm)	Fx (N)	Fy (N)	Fz (N)	RIi	Rank
#1	0.82	21.7	11.3	27.1	1.390	4
#2	0.62	34.5	20.5	24.3	1.389	5
#3	0.75	39.4	16.4	26.2	1.387	7
#4	0.49	18.4	15.2	28.4	1.394	1
#5	0.51	22.5	20.6	30.4	1.391	3
#6	0.41	29.6	19.8	31.2	1.391	2
#7	0.94	31.7	22.7	22.8	1.385	8
#8	0.82	32.7	28.6	30.6	1.383	9
#9	0.73	28.1	18.4	31.5	1.388	6

IV. Conclusion

This study performed multi-objective optimization of the grinding process for 3X13 steel. The RAM algorithm and the ENTROPY weighting method were integrated for the first time to solve the optimization problem of the surface grinding process. The weights of the criteria Ra, Fx, Fy, and Fz were determined as 0.364, 0.208, 0.218, and 0.210, respectively. The RAM algorithm identified the optimal values of workpiece velocity, feed rate, and depth of cut as 10 (m/min), 4 (mm/stroke), and 0.01 (mm), respectively. Under these optimal cutting conditions, the corresponding values of Ra, Fx, Fy, and Fz were 0.49 (μm), 18.4 (N), 15.2 (N), and 28.4 (N), respectively.

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